GEOMETRIC POTENTIAL OF IRS-1C PAN-CAMERA

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ABSTRACT:

IRS-1C images with optimal stereo relations have been used for a post calibration based on control points. The main problem was the determination of the arrangement of the three line sensors, which are combined together to a line with 12 000 pixels. A full PAN-scene is delivered as 3 separate files with 4096 * 14798 pixel. The geometric relation of the sensors has been determined empirically by means of 3 full scenes covering an area around Hannover with a base to height ratio of up to 0.8.

Based on 17 to 63 image points in the overlapping areas, the sub-scenes have been joined together. Only a shift was required, a similarity transformation has not improved the results of +/-0.2 pixel up to +/-0.5 pixel. This is representing the pointing accuracy in the images. In addition to the shift of the sub-scenes it is possible that the sensors are not aligned and they may have a different scale, caused by differing distance to the projection center. By this reason, special additional parameters corresponding to the geometric relation have been introduced into the Hannover program BLASPO for bundle block adjustment of line sensor images taken from space.

With 90 control points, digitized from maps 1 : 5000 with an accuracy of approximately SX=SY=+/-2m and SZ=+/-1m, the geometric relation of the PAN-camera has been inspected. Without use of the orbit data, just with the information about the view direction and the orbit ellipse by means of the height above sea surface, the bundle block adjustment was processed. In addition to the additional parameters describing the affinity, which is belonging to the exterior orientation, the special additional parameters for the sensor alignment and the sensor scale were required. With the two most inclined scenes a ground accuracy of SX=+/-5.5m, SY=+/-4.7m and SZ=+/-8.7m has been reached corresponding to +/-1.1 pixel. This is possible without pre-knowledge of the exact sensor geometry with a sufficient over-determination with 8 control points for the covered area of 86km * 84km. The use of the third scene is not improving the results. The achieved accuracy is mainly representing the identification of the check points, not the sensor accuracy itself. The identification of the points is influenced by long shadows, it should not be mistaken with the above mentioned pointing accuracy.

1. INTRODUCTION

The panchromatic camera (PAN) of the IRS-1C has a folded mirror telescope with a focal length of 982.45mm. It can be rotated across track up to +/- 26°. The approximately 12 000 sensor elements, each with a size of 5.84m on the ground are covering 70km in the case of a nadir view, this goes up to 91km for the most inclined view. There are no CCD-line sensors available with a pixel size of 7µm and such a number of elements, by this reason the field of view is separated into 3 parts and imaged on 3 CCD-sensors, each with 4096 pixel. The relation of the 3 CCD-lines together have to be determined. Based on points, located in the overlapping area of the 3 sub-scenes it is possible to transform the sub-scenes together. In general there are the following geometric problems:

1. the sensors may have a different focal length, that means different distance to the projection center, causing a difference in scale
2. the sensors may not be parallel to each other
3. there may not be orthogonal against the optical axis
4. there may be a shift in the image plane, different from the pre-values.

The shift of the CCD-line sensors in the orbit direction like shown on the right hand side of figure 1 and in figure 2 can be respected by a time shift, or a shift of one scene to

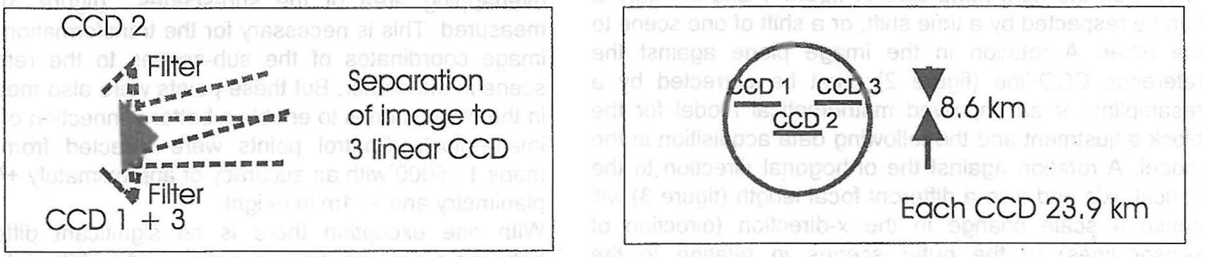

Figure 1: separation of the 3 CCD-sensors in the IRS-1C PAN-camera

the other. A rotation in the image plane against the reference CCD-line (figure 2) must be corrected by a resampling or an improved mathematical model for the block adjustment and the following data acquisition in the model. A rotation against the orthogonal direction to the optical axis and also a different focal length (figure 3) will cause a scale change in the x-direction (direction of sensor lines) of the outer scenes in relation to the reference scene in the center. There is no influence in the y-direction (orbit direction), a discrepancy of the focal length will only cause an over- or under-sampling.

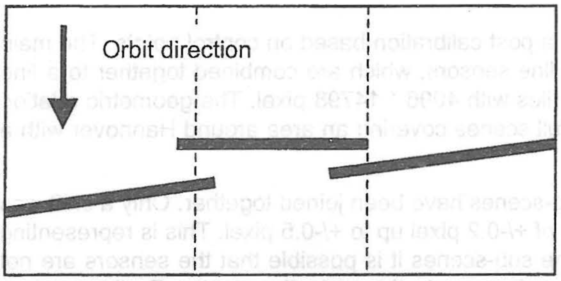

Figure 2: location of CCD-line-sensors in the image plane

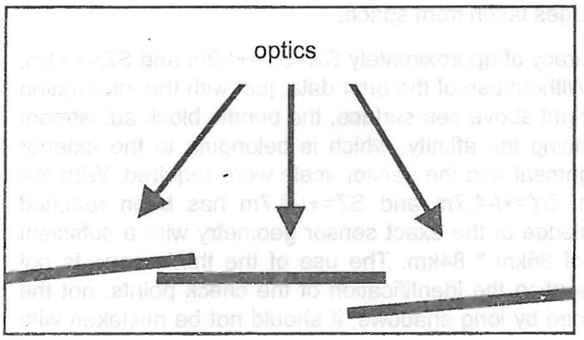

Figure 3: : location of the CCD-lines out of image plane

y-direction (orbit direction), a discrepancy of the focal length will only cause an over- or under-sampling.

2. DATA ACQUISITION AND PREPARATION

For the camera calibration 3 scenes of the area around Hannover were available. The first with a view direction of 18.7° against the nadir was taken at December 24, 1996, the second as nadir view was taken at December 25 and the third at December 26 with a view direction of −20.6°. The second scene is partly covered by clouds. A disadvantage is the low sun angle of ~13°, the long shadows, which caused some difficulties in the point identification.

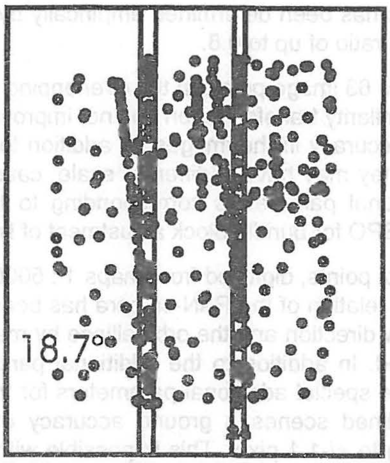

figure 5: Measured image points (image of December 24, 1996, line of tie points in the overlapping area of the sub-scenes

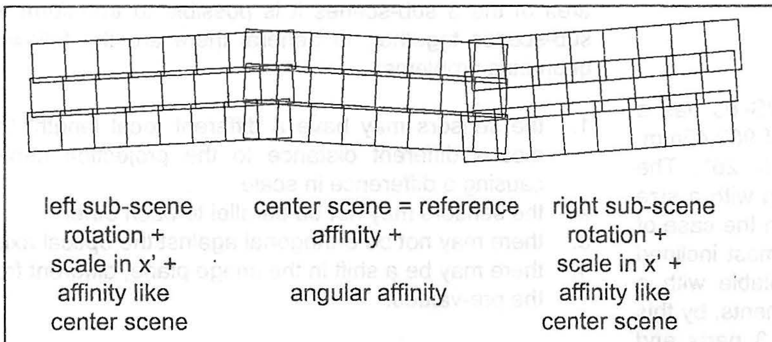

Figure 4: location of pixels in the object space
- over-sampling has no geometric influence to the whole scene

The shift of the CCD-line sensors in the orbit direction like shown on the right hand side of figure 1 and in figure 2 can be respected by a time shift, or a shift of one scene to the other. A rotation in the image plane against the reference CCD-line (figure 2) must be corrected by a resampling or an improved mathematical model for the block adjustment and the following data acquisition in the model. A rotation against the orthogonal direction to the optical axis and also a different focal length (figure 3) will cause a scale change in the x-direction (direction of sensor lines) of the outer scenes in relation to the reference scene in the center. There is no influence in the

The image coordinates have been determined with a digital stereo workstation. As a first step tie points in the overlapping area of the sub-scenes (figure 5) were measured. This is necessary for the transformation of the image coordinates of the sub-scenes to the reference scene in the center. But these points were also measured in the other scenes to enable a better connection of the 3-image-block. Control points were selected from base maps 1 : 5000 with an accuracy of approximately +/-2m in planimetry and +/-1m in height..

With one exception there is no significant difference between a similarity transformation and a shift of the sub-scenes together by means of tie points. By this reason and also because of not theoretical justification of a higher degree of transformation, only the shift has been used for the final computation of unique scene coordinates. The accuracy of ±0.2 up to ±0.7 pixel represents the accuracy of the point identification in different images, it should not be mistaken with the identification of control points. Control points may be the location of a road intersection and this can be shifted in the image caused by shadows of surrounding trees, this is the same shift for a tie points in all images, that means it will not influence the transformation of the sub-scenes, but it will have an influence to the absolute position of the control points.

image	shift x	Sx	shift y	Sy
24 shift	-4035.6	+/-0.4	29.0	+/-0.5
24 similarity 46 points	-4035.5	+/-0.3	28.2	+/-0.4
25 shift	-4042.5	+/-0.5	29.3	+/-0.7
25 similarity 17 points	-4039.6	+/-0.2	30.4	+/-0.2
26 shift	-4039.8	+/-0.2	45.1	+/-0.3
26 similarity 39 points	-4039.7	+/-0.2	44.9	+/-0.2

left scene to center scene

image	shift x	Sx	shift y	Sy
24 shift	3830.5	+/-0.4	30.3	+/-0.4
24 similarity 63 points	3831.1	+/-0.3	29.8	+/-0.4
25 shift	3823.5	+/-0.4	12.3	+/-0.4
25 similarity 25 points	3823.6	+/-0.4	11.4	+/-0.3
26 shift	3823.7	+/-0.3	1.5	+/-0.6
26 similarity 55 points	3825.1	+/-0.3	0.7	+/-0.4

right scene to center scene

table 1: Transformation of sub-scenes together
- similarity transformation and shift [pixel]
  explanation:
  image 24 = taken at December 24, 1996, image 25 taken at December 25 ...
  Sx = mean square error of shift or transformation (discrepancy at tie points)

The shift values differ significantly, that means, values of another calibration cannot be used. The shift values have to be determined individually for each scene.

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3. PROGRAM BLASPO

Line scanner like IRS-1C have perspective imaging geometry only in the sensor line direction. In the direction of the orbit the imaging geometry is close to a parallel projection. Thus, the photo coordinates as input for the collinearity equation are simplified to $\underline{x'} = (x', 0, -f)$ or $(0, y', -f)$ for stereo in track - the photo coordinate y' or x' is identical to 0.0 (by theory the image coordinate in the direction of the orbit can reach up to 50% of the pixel size). The pixel coordinates in the orbit-direction of a scene are a function of the satellite position (function of the time), or reverse, the exterior orientation of the sensor can be determined depending upon the image position in the orbit-direction. Because of the number of unknowns and the point distribution, with the traditional photogrammetric solution the exterior orientation of each single line cannot be determined. However the orientation of neighboring lines, or even in the whole scene, are highly correlated. This is different for airborne scanner where rapid angular movements can happen.

A fitting of the exterior orientation by an ellipse fixed in the sidereal system - the earth rotation has to be respected - is used. This has been shown as sufficient for other space sensors also over large distances. With at least 3 control points and a general information about the inclination, the semimajor axis and the eccentricity of the satellite orbit, the actual orbit can be computed without any use of the ephemeris. Because of an extreme correlation between the 6 traditional orientation elements (rotations and projection center), only the rotations and Zo are used as unknowns. The remaining errors of the mathematical model, especially the affinity and angular affinity have to be modeled by additional unknowns (additional parameters) in the image orientation. By this method errors of the exterior orientation caused by an inaccurate orbit or irregular movements within the orbit can be identified and modeled. This is in general the same solution like with the discrepancies of photos against the mathematical model of perspecitivity (Jacobsen 1995).

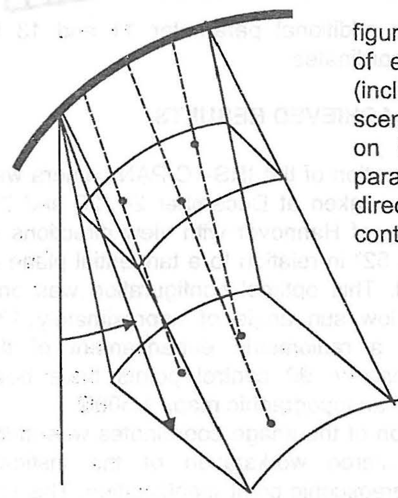

figure 6: determination of exterior orientation (including orbit in the scene area) just based on inclination, ellipse parameters, view direction and few control points

Irregular movements and rotations of the satellite and other problems of the mathematical model have to be covered by additional parameters.

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 1  Y' = Y +  P1 * Y
 2  X' = X +  P2 * Y
 3  X' = X +  P3 * X * Y
 4  Y' = Y +  P4 * X * Y
 5  Y' = Y +  P5 * SIN(Y * 0.06283)
 6  Y' = Y +  P6 * COS(Y * 0.06283)
 7  Y' = Y +  P7 * SIN(Y * 0.12566)
 8  Y' = Y +  P8 * COS(Y * 0.12566)
 9  Y' = Y +  P9 * SIN(X * 0.04500)
10  X' = X + P10 * COS(X * 0.03600)
11  X' = X + P11 * (X-14.)      if x >  14.
12  X' = X + P12 * (X+14.)      if x < -14.
13  Y' = Y + P13 * (X-14.)      if x >  14.
14  Y' = Y + P14 * (X+14.)      if x < -14.
15  X' = X + P15 *SIN(X * 0.11)*SIN(Y*0.03)
```

table 2: additional parameters of program BLASPO

The first 2 additional parameters are corresponding to an affinity deformation of the scene, they are required by the used mathematical model for the determination of the difference of the pixel size in orbit and across orbit and also for the fitting of remaining errors of the satellite inclination or horizontal satellite rotation. The parameters 3 – 8 can cover irregular movements and rotations of the satellite, they are usually not so important and they can only be determined by means of a sufficient number of control points. The parameters 11 – 14 can determine errors of the alignment and differences in the focal length of the 3 CCD-lines of the IRS-1C-PAN-camera like shown in fig. 2 and 3. The effect is limited to the left and the right sub-scene, it is starting with the x'-coordinates of -14mm or +14mm (2000 pixel x 7µm). The parameter 15 can fit remaining systematic effects.

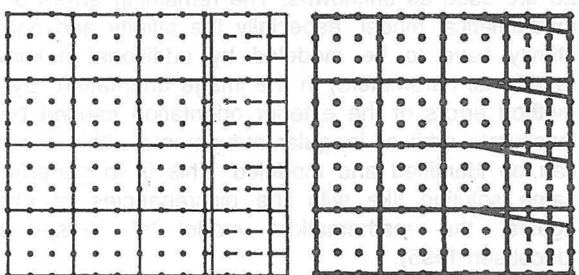


figure 7: effect of additional parameter 11 and 13 to image coordinates

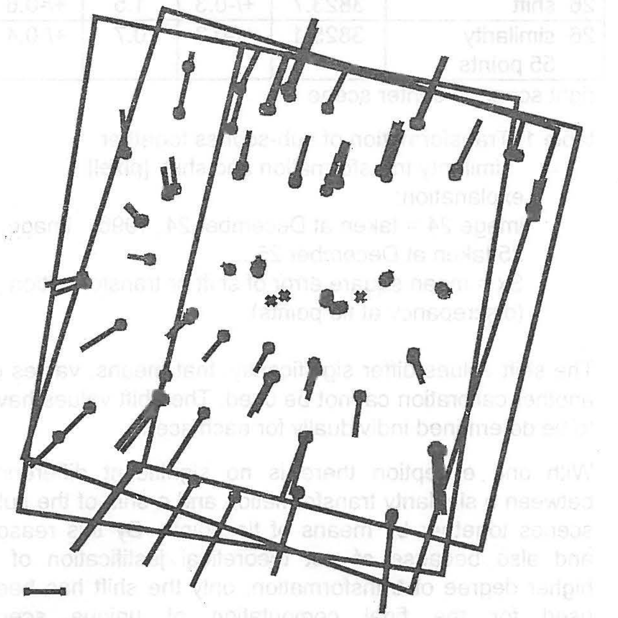
4. ACHIEVED RESULTS

The empirical calibration of the IRS-1C-PAN-camera was based on 3 scenes taken at December 24, 25 and 26, 1996 over the area of Hannover with view directions of 21.27°, 0° and -23.52° in relation to a tangential plane of the earth ellipsoid. This optimal configuration was only disturbed by the low sun angle of approximately 13°. Because of this, a radiometric enhancement of the scenes was necessary. 90 control points have been digitized from German topographic maps 1:5000.

The data acquisition of the image coordinates was made with the digital stereo workstation of the institute, supported by a stereoscopic point identification. This has improved the reliability, so finally only 5 of 90 points have been disregarded from the computation – a very small number for space images. With the original images, the stereoscopic impression is limited to the area around the floating mark because of y-parallaxes caused by the different rotations of the scenes.

adjust. (3 scenes with exception of 7)	additional parameters (if not mentioned, individually for each scene)	sigma 0 [µm]	SX [m]	SY [m]	SZ [m]
1	0	205.9	97.4	191.0	471.6
2	1 + 2	28.3	8.6	10.5	82.8
3	1,2, (11-14 for all scenes together)	27.7	8.6	7.1	83.2
4	1,2,11,12	17.3	7.0	9.4	10.5
5	1,2,13,14	23.9	9.0	5.7	84.0
6	1,2,11-14	7.9	7.1	5.0	9.7
7	1,2,11-14 only both inclined scenes	7.8	7.6	5.1	9.2
8	1 - 15	7.6	5.5	4.7	8.7
9	1,2,11-14 9 control points	5.8	8.8	5.4	10.6

table 3: results of the bundle adjustments
SX, SY, SZ = mean square error of 85 control points (in case of adjustment 9: mean square error at check points)



146m in X, Y

figure 8: adjustment (1) without additional parameters, area covered by the 3 scenes and X-Y-discrepancies at control points
- strong affine deformation caused by limited pre-information about imaging frequency (distance in orbit / Δt)

As expected, the adjustment with 4 orientation elements for each scene and without additional parameters is not leading to accurate results (table 3 and figure 8). But also the adjustment 2 with the additional parameters 1 and 2 (affinity) is leading to poor height accuracy. That means, the 3 CCD line sensors of the IRS-1C PAN-camera do not have the same focal length (see also figure 3 and 10). As third adjustment, the parameters 1 and 2 are determined individually for each scene and the deviations of the sensor alignment are modeled by the special additional parameters for the PAN-camera, the parameters 11 up to 14. In this case these special parameters are determined for all scenes together. This is justified if the relation of the CCD-lines is stable over time. But the result is only slightly improved against adjustment 2 in the Y-component, the large discrepancies in the height of the control points are still existing.

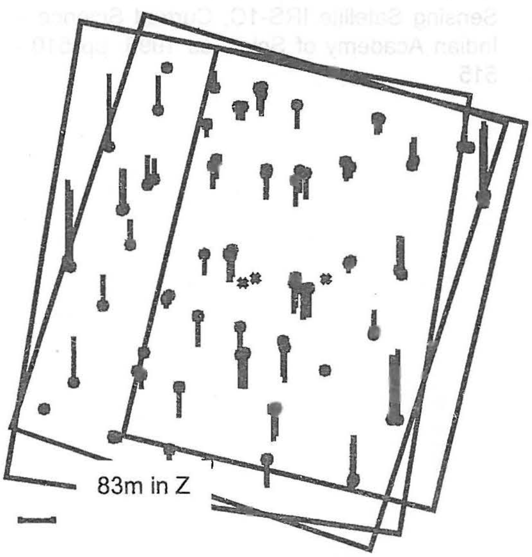


figure 9: adjustment 2 with additional parameters 1 and 2, individually for every scene, Z-discrepancies at control points
In Eastern and Western part mostly positive values, in center part negative values caused by differences in focal length for the 3 CCD-sensors

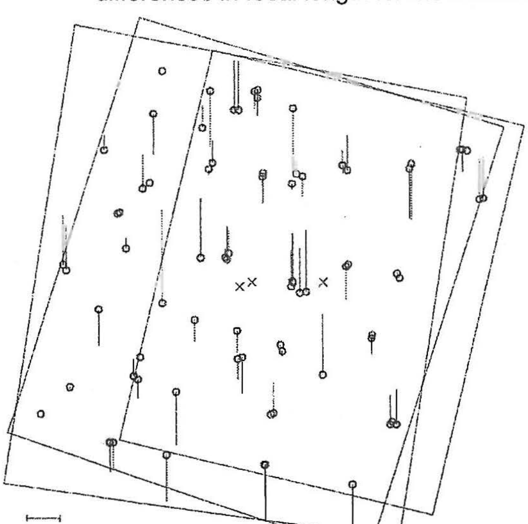


figure 10: adjustment 6 with additional parameters 1,2, 11-14 individually for every scene, Z-differences

An adjustment with the parameters 1, 2 (affinity) and 11, 12 (change of scale for the outside located CCD-lines) individually for each scene is improving the quality of the Z-component drastically from more than +/-80m to +/-10.5m. A corresponding run with the parameters 1, 2 and 13, 14 is improving the horizontal accuracy, but the height is still poor. Optimal results are achieved with the combination 1,2 and 11 up to 14 individually for each scene. That means, the CCD-lines are not exactly aligned and they do have a different focal length, causing a scale change of the corresponding sub-scenes and the geometric relation of the CCD-lines is changing over the 3 days of imaging.

The influence of the center scene to the point determination was checked with adjustment 7. Under the same condition like the preceding adjustment with 3 scenes, there is more or less no change of the quality of the results. Of course the use of only 50% of the center scene, caused by a partial cloud coverage has to be taken into account. But also in the northern part with a good overlap of the 3 scenes there is no improvement. In general the improvement of the ground coordinate accuracy by a nadir scene between 2 inclined scenes should occur only in planimetry due to the use of a third image.

There are still some remaining systematic effects at the control points shown by the covariance analysis. Up to a distance of 8km, the corrections of the control points are correlated, in the Z-component up to 0.49. Such remaining systematic effects can be modeled by the other additional parameters (3 – 9, 15). An adjustment (version 8) with all additional parameters is improving the results to SX=+/-5.5m, SY=+/-4.7m and SZ=+/-8.7m. But this can de done only with a higher number of control points.

An adjustment with such a high number of control points is required for the analysis of the sensor geometry, but is unrealistic for an operational case. Because of the special characteristic of the combination of 3 CCD-sensors in the PAN-camera, it is not possible to handle the problem with just 3 control points. Based on 9 control points (additional parameters 1,2 and 11 – 14 individually for every scene) and comparing the results with the not used points as independent check points (adjustment 9), there is only a limited reduction of the precision. The achieved accuracy of SX=+/-8.8m, SZ=+/-5.4m and SZ=+/-10.6m is sufficient for mapping in the scale 1 : 50 000.

	scene 24	scene 25	scene 26
additional parameter 11 (scale, right) = focal length	137µm	-109µm	25µm
additional parameter 12 (scale, left) = focal length	-70µm	123µm	20µm
additional parameter 13 (rotation, right) = alignment	-95µm	-182µm	-42µm
additional parameter 14 (rotation, left) = alignment	126µm	-154µm	-28µm

table 4: effect of additional parameters 11 – 14 for the most outside located parts of the combined scenes, based on adjustment 6

The achieved accuracy has to be seen in relation to the pixel size of 5.8m in the ground coordinate system and 7µm in the image. The mean of the horizontal accuracy is close to 1 pixel and in the case of the height, the base to height relation of 1 : 1.26 has to be taken into account, leading to +/-1.3 pixel in the x-parallax. Sigma0 is also in the range of 1 up to 1.4 pixel.
In table 4 the effect of the additional parameters to the outer parts of the combined scenes (pixel 0 and pixel 12 000, corresponding to –42mm and +42mm) is shown. The values are quite different for the 3 used scenes. This demonstrates again the requirement for the handling of the additional parameters 11 up to 14 individually for every combined scene. They only can be determined by means of control points well distributed over the scene. Theoretically 5 control points are sufficient, but for an operational handling also the reliability is important (figure 11).

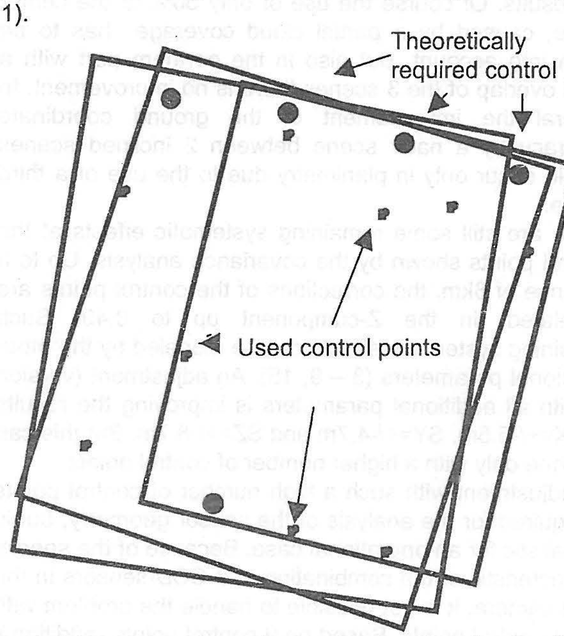


figure 11: used and required control points for the IRS-1C-PAN-block Hannover

. CONCLUSION

A bundle block adjustment of IRS-1C-PAN-scenes has led to satisfying results if special additional parameters are included which can take into account that there are 3 CCD-sensor lines in the camera. A self-calibration is required because of changing conditions. Without use of ephemeris an accuracy of approximately 1 pixel can be reached in the horizontal component and the x-parallax.
In addition to the standard configuration of just 4 control points in a stereo scene, at least 2 additional control points close to the overlapping area of the sub-scenes are required. These are more control points than necessary for a SPOT-stereo-scene, but the area covered by a complete IRS-1C-PAN-scene is 60% larger than a SPOT-scene and the PAN-camera provides a higher resolution.

ACKNOWLEDGEMENT

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